Enhanced Image Segmentation in Thermal Infrared Image Processing for Faulty Detection on Broadcasting Equipment

Mohd Rizman Sultan Mohd, Sukreen Hana Herman, and Zaiton Sharif

Abstract – **Evolution of electronics equipment evolves rapidly with the technologies invented. Broadcasting field also transform from analogue devices system into file-based system. As a continuously used equipment, the life-span is an important issue. To prevent breakdown, this broadcasting equipment must have a proper health inspection which provides an early detection for further action. This paper reports a faulty detection on broadcasting equipment with thermal infrared imaging system as a monitoring system. This study is carried out in the radio broadcasting studio which monitor the equipment through the operation time period. The data gathered from the system will undergo enhanced image segmentation method using k-means clustering with the implementation of histogram equalization for further image processing algorithm to detect the presence of hot spot. The final output image is compared with the number of hot spots detected for both images processed with implementation of histogram equalization and the image without the enhancement. Based from the result, it is shown that this proposed method successfully improved the results of the hot spot detection on thermal infrared images.**

Keywords – *Thermal Infrared Imaging, Image Segmentation, k-means clustering, Histogram Equalization*

I. INTRODUCTION

Thermal infrared had been applied in various field of interest with one of the main objectives is to detect the abnormalities in the temperature distribution on certain object. From the theory of energy, it is known that energy is recycled from one form to another form [1]. Electronic device is a transducer which converts electrical energy to heat. This heat is the by-product of electrical energy which travels freely through the circuit. If the route is blocked by malfunction component, the heat is trapped and increases as the electrical energy flows. This situation will cause a presence of hot spot that can be the factor of equipment failure.

An earlier detection of hot spot can reduce the risk of further harm on the device and reduce the down time of the equipment and eventually reduce the cost. Previously, temperature sensor will be used as a detector but the scope of detection is limited to a certain point of which the sensor is placed [2]. Having a wide scope of detection by single sensor plus to be able to see the faulty point would be the best method yet to be offered.

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These criteria would be achieved by applying thermal infrared imaging in the detection system.

II. BROADCASTING EQUIPMENT

The radio broadcasting equipment consists of several stages. These stages are interconnected with each other to form a broadcast chain [3]. The fundamental of radio broadcasting is that the sound from the studio penetrate through the air and goes straight to the listener by using frequency modulation technique [4]. This sound consists of the voice of the presenters and the music they played on the system. Entire workflow of the radio broadcast is shown in Fig.1 below.

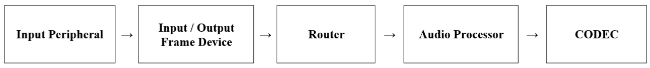


Fig. 1. Basic block diagram for radio broadcasting equipment

The 5 stages of radio broadcasting equipment start with input peripheral. In this stage, the audio is gathered from many sources. This will be used as the input audio for the program to be aired. This sources input will be connected together and controlled by the Input / Output Frame (I/O Frame) Device. In this second stage, the audio mixer will act as a control interface for the entire sources. The third stage consist of a Router. This Router is used for matrix patching and audio level monitoring. The patching including five (5) type of routing exercise as stated below:

1. Analog to Digital
2. Analog to Analog
3. Digital to Analog
4. Digital to Digital
5. GPIO handling

This routing will use either digital copper, digital Ethernet or standard analog cable. The fourth stage is the last stage for audio processing line of the broadcast station which will either increase or decrease the level of the audio to be broadcasted. The fifth and the last stage of radio broadcasting workflow before going through the transmission line is the CODEC stage. The CODEC stage is handled by the transmission service provider. In this stage, the audio will be encoded to meet the required signal before it will be sent to the transmission site. As for this study, we focused on broadcasting equipment in the studio.

III. THERMAL INFRARED MONITORING SYSTEM

The ability to trace the faulty without any infiltration is the main reasons of having thermal infrared imaging. Thermal infrared imaging starts with the discovery of the red-light spectrum which has unique presentation [5]. Infrared can be divided into three layers of near, mid and far [6]. These layers have its own unique characteristics. Far-infrared layer or in other word, thermal infrared layer is responsible in representing the whole body of matter into temperature representative image called thermogram if only the matter has temperature above absolute zero values [7]. Fig.2 show the block diagram of the thermal infrared system consists of the optical lens, IR detector and electronics circuit. The optical lens used to focus entire light source before it going through the IR detector where the image will be presented on screen based on its temperature distribution. The resulted image from the detector is called thermograms. Thermograms contained temperature information together with the glimpse of the normal images. The electronics circuit on the device works as ordinary camera whereas the thermogram will be presented in digital image form.

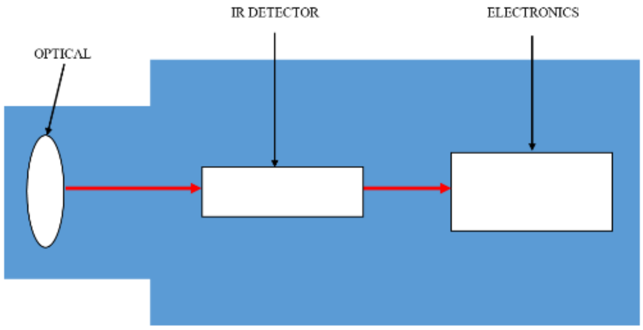


Fig. 2. Thermal infrared device configuration.

Thermal infrared imaging system is widely applying to various field of interest including medical approach [8-10], disaster risk evaluation [11], security and surveillance system [12], performance evaluation [13], hazard determination [14], and hot spot detection system in electronic devices, electrical appliances and heavy-duty electrical-mechanical equipment [15]. The main reasons of having thermal infrared as temperature detection tools is because it is non-contactable detector [16], maintenance-free devices in most of application [17], cost saving approach [18] and automation enable configuration [19].

Thermal infrared senses the temperature of an object regardless of the condition of the lighting in the surrounding. It captures image even in the dark. Ability to see threat before it become worse, the thermal infrared gives the real situation happening in temperature distribution within the equipment and sense the hot spot before it causes further damage into the system and in worse case, fire accident. From the statistic data given by the Fire and Rescue Department, it is reported that the highest case of fire is caused by an electronics and electrical equipment [20]. Even though the devices is equipped with the heat sink and other safety features, the faulty components will always be the culprit and drag the whole device into fatality.

By having thermal infrared monitoring system, the abnormalities within the whole picture of the equipment is been captured and surpass the ability of thermal sensor which sense the temperature at certain point only. Having thermal infrared camera only doesn't solve the problem yet. Because the thermal infrared camera only captured the images. These images had to be interpreted by supervision for further clarification and understanding. That is why, image processing is needed in the system chain. It will be the guide in faulty detection by tracing the red dot or red entity in the image loaded. The detection system is written in the MATLAB R2015a software. MATLAB is a scientific programming software which allow a deep analysis especially referring to an image processing [21].

IV. Faulty Detection Method

This paper presents the Faulty Detection Method for Broadcasting Equipment using thermal infrared imaging system. The method is proposed because there is no indicator which sense the abnormalities of temperature distribution on the equipment at present. The thermogram obtained from the thermal camera will be processed using image segmentation method of k-means clustering. This paper also presents the introduction of histogram equalization in the image processing. The results will be compared and discussed further in this paper.

This abnormality is defined as a hot spot which could occur everywhere in the equipment. The presence of hot spot would lead malfunction on certain component. With the current flow in the circuit thru the faulty component, the heat will increase and burned. This small spark would trigger much more fatality if there is no action taken on the scene. To avoid further losses to the stakeholder, earlier prevention system is needed. Basically, the faulty detection method setup is shown as Fig.3 below:

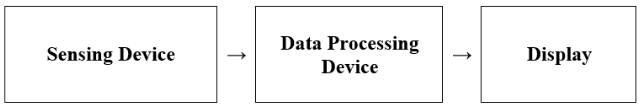


Fig. 3. Basic block diagram for a faulty detection system

Faulty detection starts with the sensing devices which had many variety and choices. Sensing device reads the data and transfer it to the data processing devices. The devices will collect the data and processed to form a single data representation. Finally, the data will be displayed as a final product.

As for temperature sensing, there are two main device that are widely used; temperature sensor and thermal infrared sensor. The main different between these two sensors is that temperature sensor is attached to the object while thermal infrared sensor offer non-contact sensing for temperature. There are many thermal infrared cameras available in the market for various purposes. But the similarity of the product is that, it is limited to the capture and display only. That is why, the smart sensing is needed especially for a faulty tracing.

V. Proposed Method

With the available technologies in the market, the application of thermal infrared monitoring becoming simple and ease to used. This paper proposes a simple setup for gather the data in term of thermal image and send it to the computer for image processing to act. There are two steps of this proposed method;

hardware setup and proposed algorithm for the image processing.

A. Hardware Setup

The needs of portable device because it will be used as a daily health monitoring device for maintenance routine. This real-time inspection must be done without any interference with the live-cast event being held in the studio. With the smartphone attached with the FLiR One, the thermal images captured can be send through wireless photo transfer application; WiFi Photo available for both Android and iOS-based application. The application connected with the computer in the control room with the specific IP address to allow images loaded to the image processing software; MATLAB. The workflow of the hardware setup in this study is shown in Fig.4 below:

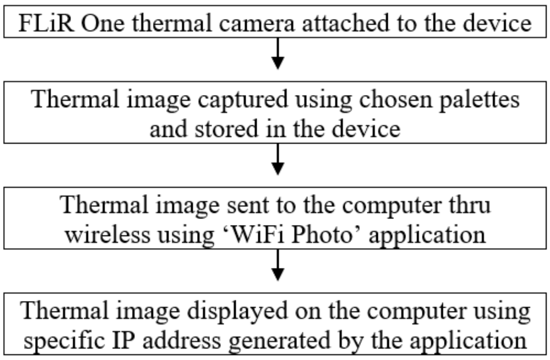


Fig. 4. The workflow of the hardware setup.

The thermal image taken and send to the main computer at the Main Control Room (MCR) for further analysis while, technical person doing the inspection could also take a necessary action to eliminate the risk of faulty on the system. As for this study, the data collected during aired program held on the broadcasting studio.

Fig.5 shows the two main part of the radio broadcast system. The first part labeled as block A is the main system while block B is the secondary system. Block A is the computer system consist of three main function which are the audio server, on-line system and I/O frame controller. Block B consists of hybrid telephone system, I/O patching and audio DVD player. Fig. 6 and Fig.7 show more focused image of block A and block B setup.

Based from the Internal Faulty Report by the technical team, these two parts tend to have malfunction due to the error in the computer system and power supply issue. The power supply is directly from the 3-phase supply. In the case of power interruption, the power supply is backed up by the Uninterrupted Power Supply (UPS).

Fig. 5. Actual setup for radio broadcast studio.

Fig. 6. Block A.

Fig. 7. Block B.

B. Image Processing Method

The second part of the system is continued with MATLAB R2015a image processing software. The captured thermal images are processed using proposed method. This proposed method is an enhanced image segmentation method using k-means clustering with the histogram equalization. The workflow of the method starts with the image acquisition which the thermogram is received from the devices using the WiFi transferring medium. The thermogram then undergone histogram equalization process where the image intensities are adjusted to enhance its contrast. Fig.8 below shows overall image processing method applies to the thermogram.

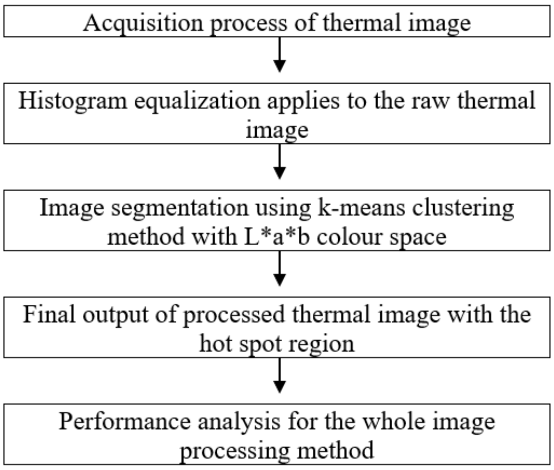


Fig. 8. Overall flowchart of the image processing.

Fig. 9. Raw thermogram captured by FLiR One thermal camera.

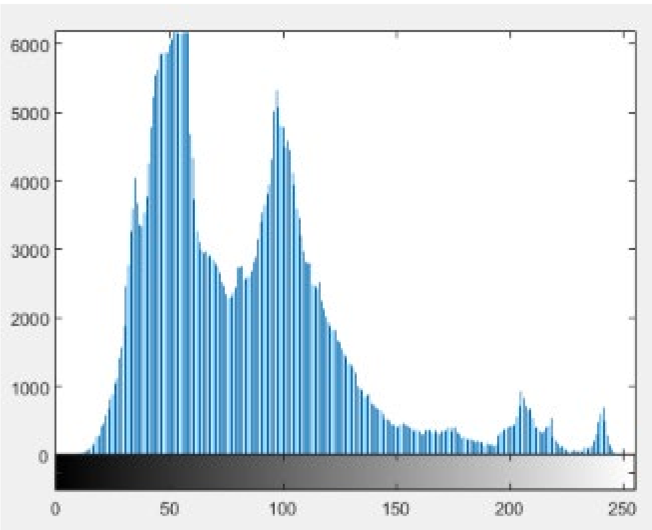


Fig. 10. Associated histogram graph for raw thermogram in Fig.9.

Fig. 11. Thermogram after processed by histogram equalization.

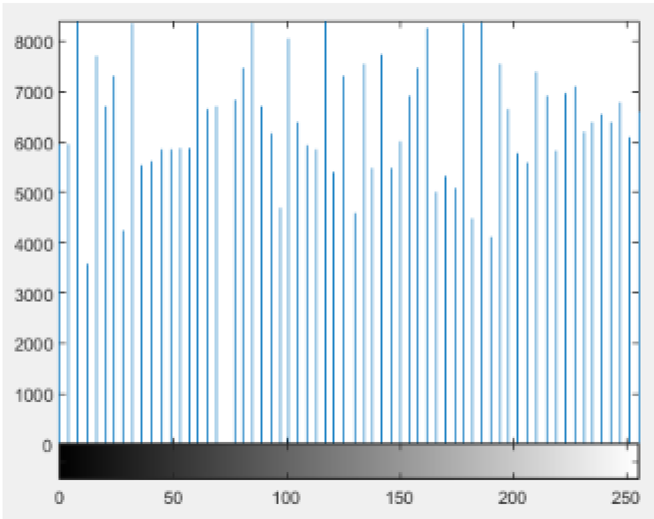


Fig. 12. Associated histogram graph for thermogram in Fig.11.

Fig. 11 shows the resultant thermogram after being processed through histogram equalization. The different can be seen through the thermogram itself and also the histogram graph both shown in Fig.10 and Fig.12. Before thermogram enter the image segmentation process, it must be first converted into RGB image. Thus, requires a conversion from grayscale image into RGB image using pseudo-color technique. Fig.13 shows the resultant thermogram after converted into pseudo-color image.

K-Means performs an identification tasks which classes the given data set according to given criteria in the given the segmentation of the instance space, into regions of similar objects. K-Means is an unsupervised iterative and heuristic partitioning algorithm based on clustering method [22]. This criterion made it become inevitable for pattern recognition system, classification analysis, image processing and application on intelligence system including machinery vision [23-24].

Given a set of d-dimensional real vector data (x1 , x2 ,… xn). K-Means clustering perform partitioning tasks of the nobservation into K(< n) sets S = { S1 , S2 , … Sk } to minimize the within-cluster sum of distance functions of each point in the cluster to the K-center. The formula (1) below show the K-Means function:

$$\arg_s \min \sum_{i=1}^{k} \sum_{x \in S_i} \| x - \mu_i \|^2 \quad (1)$$

Where μ_i is the mean of points in S_i.

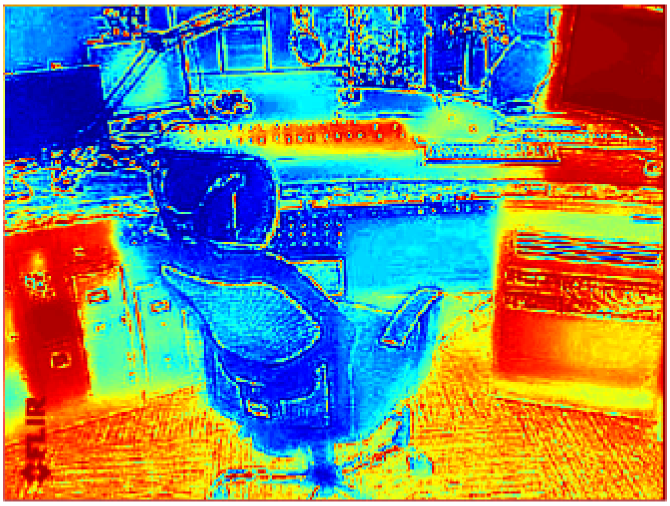


Fig. 13. The pseudo-color image of thermogram.

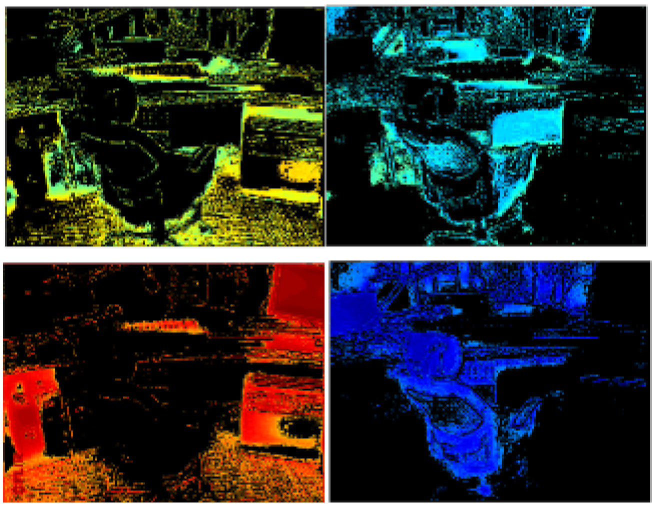


Fig. 14. Segmented thermogram according ot its mutual layer.

By using K-Means clustering, the thermogram is divided into several layer. Each layer contains individual group of color. With K-Means, the red-region layer can be segmented and separated from the pseudo-color image and then blend together with the initial raw thermogram loaded earlier in the program. As a result, the thermogram is shown with the red-colored region as shown in Fig.14 below.

This red colored region is chosen because the hot spot in the image is shown in red-colored region on thermal infrared images. The red colored region is blend with the earlier thermogram image which had been processed using histogram equalization. The idea of this process is to show the red colored region in the thermogram to ease the technical operator to observed and detect the hot spot in the broadcasting equipment.

Fig. 15. Final output of the proposed method.

The performance for both k-means clustering method and enhance k-means clustering method for thermal image, the Peak Signal to Noise Ratio (PSNR) is calculated [25].

$$PSNR = 10 \log \frac{255 * 255}{MSE} dB \quad (1)$$

Where MSE is mean square error [26]. It is ideally infinity but in practical it is I the range of 25-40 dB.

$$MSE = \frac{\sum_{M,N} [I_1(m,n) - I_2(m,n)]^2}{M * N} \quad (2)$$

PSNR computes ratio between two images and often used as a quality measurement tools between input image and processed image. The higher PSNR value, the better quality of the reconstructed image and as for MSE, the lower its value, lower the error. MSE and PSNR are two error metrics applies in image compression quality comparison. MSE represents a cumulative squared error between processed and original image while PSNR represents a measurement of peak error.

VI. Results

The image processing system proposed in this study applies to the raw thermal images captured by the portable device setup. The processed image with enhancement is compared with the image without enhancement. Both of the images are then compared using its PSNR and MSE value. Table below shows the performance of hot spot detection based on actual hot spot, previous method performance and proposed method performance. The image is separated into two blocks; Block A and Block B.

TABLE I: COMPARISON FOR BLOCK A

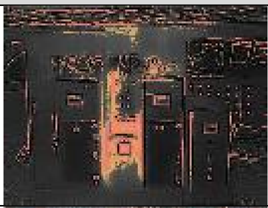
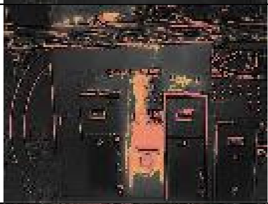
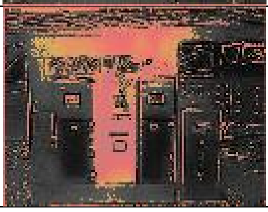
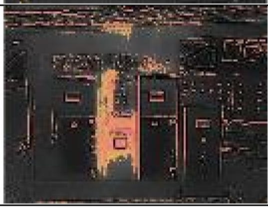
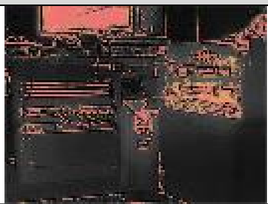
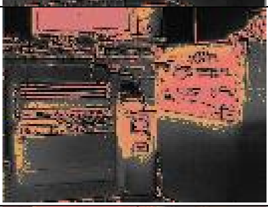
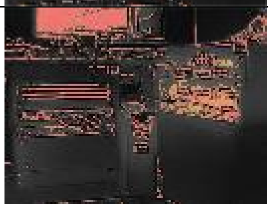
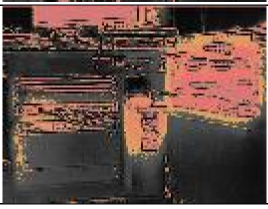
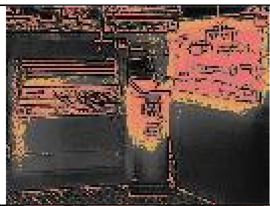
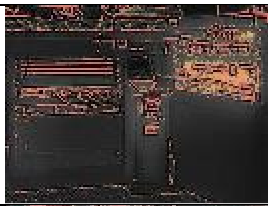
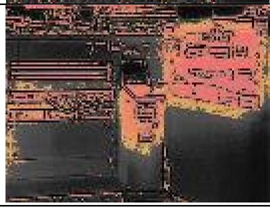
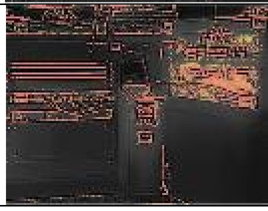
Days	***With Enhancement***	***Without Enhancement***
1		
2		
3		
4		
5		

TABLE II: COMPARISON FOR BLOCK B

Days	***With Enhancement***	***Without Enhancement***
1		
2		
3		
4		
5		

Based from results, it is shown that the application of histogram equalization as an enhancement for image segmentation manage to reveal the hot spot in the broadcasting equipment system. It is tally with the results obtained using FMEA approach which indicates that the Uninterruptable Power Supply (UPS) unit is the most affected equipment of entire broadcasting system. The collective temperature data obtained from the broadcasting equipment also shown that the temperature rises with the effect from over-heating UPS. The Peak Signal to Noise Ratio (PSNR) and Mean Square Error (MSE) calculation between both thermal image with and without enhancement is calculated MATLAB R2015a and the results shown in table below.

TABLE III: PSNR AND MSE FOR BLOCK A

Image	***PSNR value (dB)***	***MSE value (dB)***
1	15.82	1715.90
2	15.38	1896.75
3	15.41	1884.94
4	16.15	1591.02
5	15.35	1910.52

TABLE IV: PSNR AND MSE FOR BLOCK B

Image	***PSNR value (dB)***	***MSE value (dB)***
1	16.56	1447.06
2	15.68	1770.87
3	15.78	1732.48
4	15.85	1705.31
5	16.30	1535.85

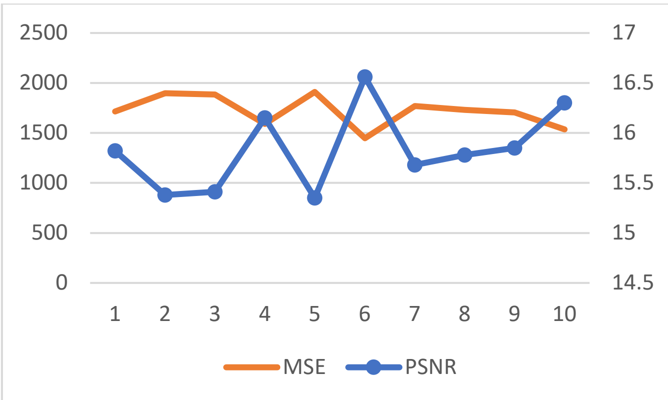


Fig. 16. PSNR and MSE chart for proposed method.

Number of detections from the method with and without enhancement are compared with the actual results of hot spot detection by using FMEA approach. It is shown that proposed method shows significant results and aligned with the actual results compared with the image segmentation without histogram equalization method. The performance graph for ten (10) samples of thermal images of broadcasting equipment is shown in Figure 17 below.

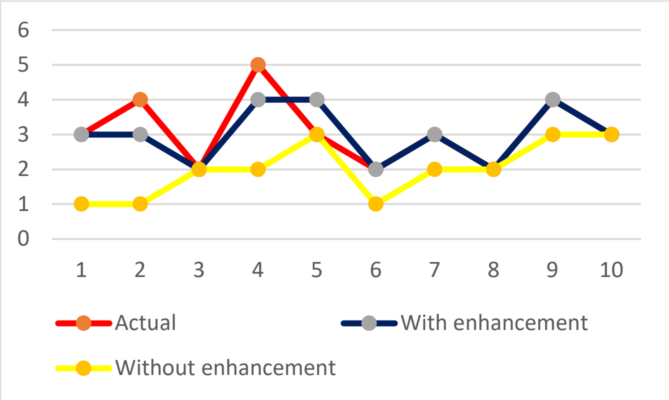


Fig. 17. The performance graph for proposed method.

VII. CONCLUSION

Based from the result, thermal infrared imaging approach had managed to detect the faulty on broadcasting equipment. This simple setup using the combination of FLiR One thermal camera and iOS device as the hardware and MATLAB R2015a image processing method using enhanced image segmentation of k-means clustering method with implementation of histogram equalization had manage to perform abnormalities detection in temperature distribution on the broadcasting equipment thus given a hint of faulty component before major breakdown happen. The thermal infrared system also introduces to replace the present method of Failure Mode and Effect Analysis (FMEA) which had been used as abnormalities and fatality detection method to overcome and eliminate the risks of having problem in the whole broadcasting equipment system.

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